

β Lyrae as Seen by BRITE in 2016

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The BRITE-Toronto (BTr) and UniBRITE (UBr) satellites observed β Lyrae from May to October 2016 to continuously monitor light-curve instabilities with the time resolution of about 100 mins. An instrumental problem affecting localized patches on the BTr CCD detector has been discovered by comparison with partly simultaneous UBr observations; the origin of the problem is being investigated. A zero-point offset permits utilization of the BTr data for a time-series characterization of deviations from the mean light curve defined to $\simeq 0.0025$ mag.

1 Introduction

β Lyrae (HD 174638) is a bright ($V_{\max} = 3.4$ mag, $B - V = 0.0$ mag) eclipsing binary with the orbital period of $P = 12.915$ days, consisting of a B6-8 II star and an invisible component which eclipses the B-type star, but otherwise is very hard to detect and characterize. The B-type star has the mass of about $3 M_{\odot}$ while the estimated mass of the invisible star is about $13 M_{\odot}$. The invisible component is apparently completely shrouded by a toroidal accretion disk formed by matter continuously transferring from the B-type star. The mass transfer results in the period lengthening at an almost constant rate of 19 seconds per year; as the result, the eclipses have shifted in time – relative to a linear prediction – by several orbital cycles during the two and half centuries of the photometric observations of β Lyrae. The complex structure of the system and its extensive studies are described in a highly readable review by Harmanec (2002). Among the more recent research of particular note are the efforts at the interferometric imaging of the binary by the CHARA array by Zhao et al. (2008) and Bonneau et al. (2011) while the latest among several β Lyrae models are by Mennickent & Djurašević (2013).

Light curves of β Lyrae have been known to show a relatively large scatter. An international campaign organized in 1959 (Larsson-Leander, 1969a,b) gave indications that the scatter may reach 0.1 mag (see fig. 8 in Larsson-Leander, 1969a) and

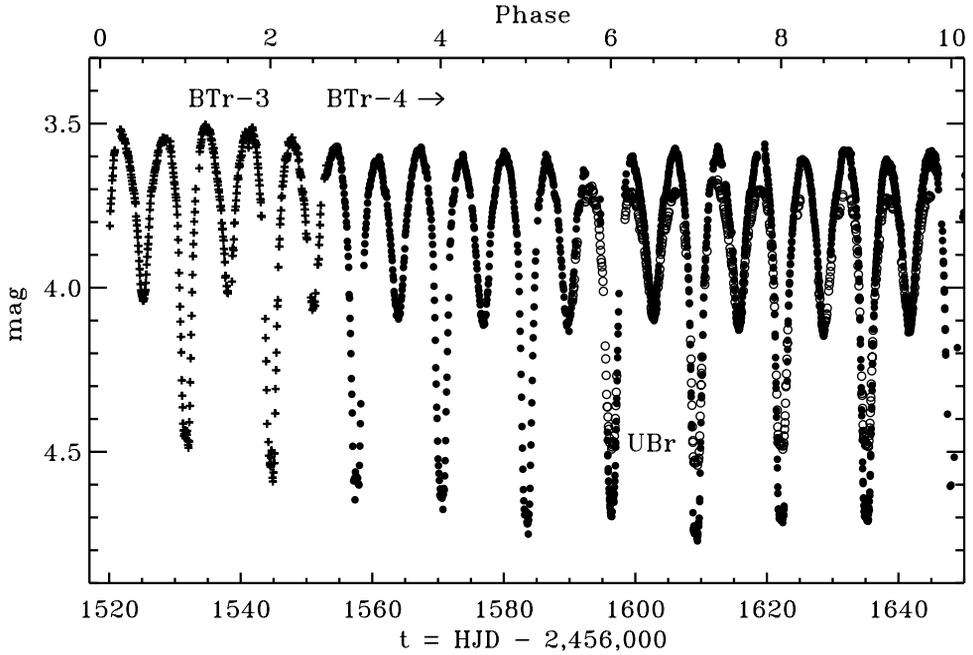


Fig. 1: BRITE observations of β Lyrae in 2016. The symbols and labels relate to different setups of the red-filter satellites, as described in the text. Note the larger amplitude of the BTr variability compared with that for UBr. This difference alerted us about a previously unrecognized CCD charge-transfer problem affecting BTr. It may – locally – affect the two remaining red-filter BRITE satellites (Sect. 3).

confirmed that it is not due to difficulties with photometric observations of bright stars or to large angular distances to comparison stars, but is definitely caused by the star itself. Later multi-spectral observations and several efforts at modelling of the binary led to a firm conclusion that the mass transfer and accretion processes are unstable and cause photometric instabilities. However, those instabilities remain poorly characterized, mostly because of the moderately long orbital period and the diurnal interruptions of ground-based observations. A possibility of a continuous photometric monitoring over several months was the driver for the BRITE Constellation observations of β Lyrae reported here.

2 Observations

The BRITE Constellation observations of β Lyrae were made between 4 May 2016 and 3 October 2016, for 152 days. Two red-filter satellites, UniBRITE (UBr) and BRITE-Toronto (BTr) and one blue-filter satellite, BRITE-Lem (BLb), were dedicated to these observations. Technical difficulties with BLb permitted the blue-filter observations for only a fraction of one binary cycle between $t = 1635$ and 1647 ($t = \text{HJD} - 2\,456\,000$) making these observations useless for the current purpose.

The results for the red-filter satellites are shown in Figure 1 using different symbols for the satellite-orientation and the initial image-processing “setups”. Since the

setups involved possible zero-point magnitude shifts, a decision was made to use only the longest time series designated as BTr-3, BTr-4 and UBr (i.e. the combined setups UBr-1 and UBr-2). The BTr observations were made with the same exposure time of 3s resulting in a median error per a single observation of 0.014 mag. For the UBr observations with 1 sec exposures, the median error was 0.019 mag. Most of our analysis has been done with the orbit averages. The satellite-orbit sampling corresponded to 98.27 minutes (BTr) or 100.4 minutes (UBr).

3 An instrumental problem

The BTr observations provided an excellent record of the variability of β Lyr sampled almost continuously for 132 days (over 10 binary orbits) at 98 minute intervals. The BTr-3 series extended from $t = 1520$ to 1553 while the BTr-4 from 1553 to 1652. The BTr-4 series overlapped for 50.1 d (3.87 orbital cycles of the binary) with the UBr observations providing a crucial check of consistency of results for both satellites. The check revealed a problem: While the UBr observations showed an expected amplitude of about 0.85 mag, the amplitude from the otherwise excellent BTr series turned out to be larger than one magnitude. Such large amplitude was never observed before. We had no previous indications of any nonlinearities in the BTr data. It became obvious that we were seeing a new instrumental problem.

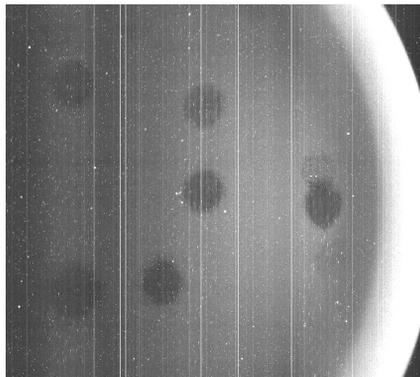


Fig. 2: A section of the BTr full-frame image dominated by the Earth-shine background signal. Note the presence of elliptical signal depressions. They are very shallow and thus affect images of faint stars to a stronger degree. Similar blemishes appear to be present locally on the CCD detectors of the UBr and BTr satellites. In this picture, the depressions have been made better visible by enhancing the contrast through histogram stretching.

An investigation of an older, full-frame image from BTr showed that the CCD background does show very shallow depressions of similar shape and size (Fig. 2). Apparently, the image of β Lyr happened to be located in one of such blemishes. Further work attempting to characterize the problem has revealed that: (1) All three red-filter satellites show the blemishes to some degree, but they do not seem to be present in the two blue-filter satellites. (2) The blemishes are very similar in terms of their size and shape in all three red-filter satellites. The problem is currently intensely investigated in order to characterize it and invent methods of its mitigation. New, full-frame data are currently being collected for all the satellites.

This is a tedious and slow process and has a detrimental impact on the ongoing science operations. All indications are that it is related to the particle-radiation damage to the CCD detectors causing charge transfer and trapping effects. However, it is not clear why only the red-filter satellites are affected and why the signal-loss areas are so similar in size ($\simeq 200$ pix) and depth (about 50 ADU). It is possible that a cloud of secondary particles is released from an optical element (a lens or filter) when it is hit by an energetic, primary particle (proton); the distance between CCD and the optical element would then determine the size of the affected region.

An attempt has been made to salvage the otherwise excellent BTr data for β Lyr. The presence of background blemishes suggested that some sort of a process modified the signal which – by itself – retained linear properties. We assumed that the CCD signal was modified by removal of a constant amount C . This led to a smaller detected signal, $s(t) = S(t) - C$, with an increased degree of modulation and thus a larger, observed amplitude of β Lyr. This way we could restore $S(t)$ by assuming that the amplitude of light variations observed by BTr must be the same for the overlapping UBr observations; obviously, a second assumption was made that observations from UBr had not been affected by a similar problem. The mapping turned out to be excellent with a perfect match of the two fluxes variations. Thanks to the very large number of the observations we could determine the lost signal to be 0.2559 ± 0.0007 of the maximum-light β Lyr signal. While the correction applies strictly to the BTr-4 setup, we used it also for the BTr-3 series because the star remained in the same location on the CCD detector. Still, for a study of the light-curve deviations, the two time series must be done separately because of the possible small zero-point magnitude shift between the setups, although a combined, phase-binned light curve (see below) indicates a perfect agreement between the two datasets.

4 The phase-binned light curve

The satellite-orbit averaged data consist of 410 BTr-3, 1230 BTr-4 and 479 UBr observations with the scatter estimated from individual data points of 0.0017, 0.0013 and 0.0019 mag, respectively (median errors); the small errors are obviously due to the large number of averaged data points. Although deviations from the mean, phase-binned BTr light curve (Fig. 3) reach ± 0.04 mag, the median errors per 0.01 phase interval are typically at the level of 0.002 – 0.003 mag. Such a well defined light curve appears to be of interest for improvement of the β Lyr system models; a preliminary use of the current light curve was presented by KP at the EWASS Conference¹. The flux derivative $df/d\phi$ computed using the light curve is smooth so that its inflection points confirm the predicted eclipse contact phases. It is interesting that small, but fairly well defined additional notches in the derivative seem to appear slightly beyond the contact phases, at approximately similar distances; they may indicate the presence of matter distributed in the system above the disk/star surfaces.

5 Conclusions

The instrumental problem that we detected in the BTr data in the β Lyr observations is currently investigated as it may be occurring in all three red-filter satellites. A

¹European Week of Astronomy and Space Science, Prague, 26-30 June 2017 (no publication).

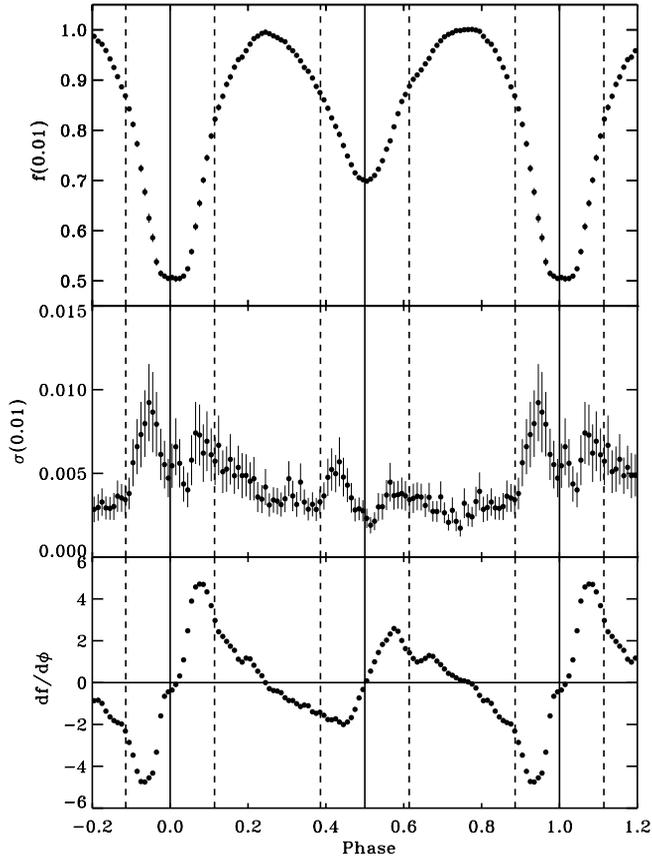


Fig. 3: The phase-binned light curve of β Lyr formed from the combined BTr-3 and BTr-4 datasets is expressed here in relative flux units per 0.01 phase interval (the upper panel). Since epoch-to-epoch averaging is involved, the errors (the middle panel) are the largest in the eclipse branches, i.e. where the absolute value of the flux derivative $|df/d\phi|$ is the largest (the lowest panel). The broken lines indicate the phases of external eclipse contacts as in the unpublished star-disk model by Pavlovski et al. (2017).

simple, linear signal transformation has permitted to correct the time series of BTr data. This time series is unique as it extends for over 10 orbital cycles of a continuous and frequent ($\simeq 98$ min) time sampling. The data will be the subject of a time-series analysis while the mean light curve will be used for a β Lyr modelling.

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